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IS/IEC 60793-1-22 (2001): Optical fibres, Part 1: Measurement methods and test procedures , Section 2 Length measurement [LITD 11: Fibre Optics, Fibers, Cables, and Devices]

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भारतीय मानक

प्रकाशिक तंतु

भाग 1 मापन विधियाँ और परीक्षण प्रक्रियाएँ

अनुभाग 22 लम्बाई मापन

Indian Standard

OPTICAL FIBRES

PART 1 MEASUREMENT METHODS AND TEST PROCEDURES

Section 22 Length Measurement

ICS 33.180.10

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BUREAU OF INDIAN STANDARDS
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NEW DELHI 110002

July 2009 **Price Group 10**

Fibre Optics, Fibres, Cables and Devices Sectional Committee, LITD 11

NATIONAL FOREWORD

This Indian Standard (Part 1/Sec 22) which is identical with IEC 60793-1-22 : 2001 'Optical fibres — Part 1-22: Measurement methods and test procedures — Length measurement' issued by the International Electrotechnical Commission (IEC) was adopted by the Bureau of Indian Standards on the recommendation of the Fibre Optics, Fibres, Cables and Devices Sectional Committee and approval of the Electronics and Information Technology Division Council.

The text of IEC Standard has been approved as suitable for publication as an Indian Standard without deviations. Certain conventions are, however, not identical to those used in Indian Standards. Attention is particularly drawn to the following:

a) Wherever the words 'International Standard' appear referring to this standard, they should be read as 'Indian Standard'.

b) Comma (,) has been used as a decimal marker, while in Indian Standards, the current practice is to use a point (.) as the decimal marker.

In this adopted standard, reference appears to the following International Standard for which Indian Standard also exists. The corresponding Indian Standard which is to be substituted in its place is listed below along with its degree of equivalence for the edition indicated:

International Standard	*Corresponding Indian Standard*	*Degree of Equivalence*
IEC 60794-1-1 : 1999 Optical fibre cables — Part 1: General specification — Section 1: General	IS 13882 (Part 1/Sec 1) : 2001 Optical fibre cables: Part 1 General specification, Section 1 General	Identical

The technical committee responsible for the preparation of this standard has reviewed the provisions of the following International Standards and has decided that they are acceptable for use in conjunction with this standard:

International Standard	*Title*
IEC 60793-1-40 : 2001	Optical fibres — Part 1-40: Measurement methods and test procedures — Attenuation
IEC 60793-1-42 : 2001	Optical fibres — Part 1-42: Measurement methods and test procedures — Chromatic dispersion

Only the English language text in the International Standard has been retained while adopting it in this Indian Standard, and as such the page numbers are not the same as in the IEC Standard.

For the purpose of deciding whether a particular requirement of this standard is complied with the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

Indian Standard

OPTICAL FIBRES

PART 1 MEASUREMENT METHODS AND TEST PROCEDURES

Section 22 Length Measurement

1 Scope

This part of IEC 60793 establishes uniform requirements for measuring the length and elongation of optical fibre (typically within cable).

The length of an optical fibre is one of the most fundamental values and shall be known for the evaluation of transmission characteristics such as losses and bandwidths.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60793-1-40, *Optical fibres – Part 1-40: Measurement methods and test procedures – Attenuation*

IEC 60793-1-42, *Optical fibres – Part 1-42: Measurement methods and test procedures – Chromatic dispersion*

IEC 60794-1-1, *Optical fibre cables – Part 1-1: Generic specification – General*

3 Overview of method

This standard gives five methods for measuring length, which are presented in the following table 1.

Table 1 – Measurement methods

Method	Characteristics covered	Fibre category(ies) covered	Former designation
A Delay measuring	Length	All A1 and all B	IEC 60793-1-A6
B Backscattering	Length	All A1 and all B	IEC 60793-1-C1C
C Fibre elongation [a]	Fibre elongation	A1 and B1 [b]	IEC 60793-1-A7
D Mechanical	Length	All	IEC 60793-1-A5
E Phase shift	Length	All A1 and all B	IEC 60793-1-A8

[a] The measurement of fibre elongation, method C, is part of several measurement methods for fibres and fibre optic cables, such as those in IEC 60794-1-1.

[b] This measurement is applicable unreservedly to type B single-mode fibres. For type A1 multimode fibres, take particular care when interpreting the results because the results of this measurement may be influenced by interfering modal effects, for example, due to the occurrence of non-longitudinal stresses on the fibre. Application of the measurement to A2 to A4 multimode fibres is under consideration.

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Information common to all measurements is contained in clauses 2 to 8. Information on specific application appears in annexes A, B, C, D, and E for methods A, B, C, D and E, respectively.

3.1 Method A – Delay measuring

The delay measuring method applies to measurements of the fibre length by the measurement of the propagation time of an optical pulse or a pulse train on the basis of a known value of the group index of the fibre.

Alternatively, this method is suitable for measuring the group index of a fibre of known length. Therefore, in practice this fibre length measurement method is calibrated against a known length of fibre of the same type.

3.2 Method B – Backscattering

The backscattering method, which is a single-sided measurement, uses an optical time domain reflectometer (OTDR), and measures the optical power backscattered from different points in the fibre to the beginning of the fibre.

3.3 Method C – Fibre elongation

This measurement method describes a procedure for determining the fibre elongation. It does not measure absolute strain, but instead measures the changes in strain from one loading condition to another.

3.4 Method D – Mechanical length

This measurement method describes a procedure for determining the fibre length by winding a fibre around a fixed diameter calibrated wheel that rotates. The length is determined by the number of revolutions of the wheel.

3.5 Method E – Phase shift

The phase shift method describes a procedure for determining the fibre length. The length is determined from the phase shift that occurs when a predetermined modulation frequency f_{max} is applied.

3.6 Reference test method

The reference test method (RTM), which shall be the one used to settle disputes, varies depending on whether the fibre is cabled or not, such as

- uncabled fibre: method D;
- length of fibre within cable: method B;
- elongation of fibre within cable: method C;
- elongation of uncabled fibre: method C.

4 Apparatus

Annexes A, B, C, D and E include layout drawings and other equipment requirements for each of the methods A, B, C, D and E, respectively.

5 Sampling and specimens

See the appropriate annex A, B, C, D or E for specific requirements. General requirements follow.

Prepare a flat end face, perpendicular to the fibre axis, at the input and output ends of each specimen for measurements based on optical delay measurements.

6 Procedure

See the appropriate annex A, B, C, D or E for specific requirements.

7 Calculations

See the appropriate annex A, B, C, D or E for specific requirements.

8 Results

The following information shall be provided with each measurement:

- date and title of measurement;
- identification and description of specimen, including whether fibre or cable;
- specimen length, or elongation;
- measurement method used: A, B, C, D or E;
- other results, as required by the appropriate annex, A, B, C, D or E.

The following information shall be available upon request:

- description of measurement apparatus arrangement;
- type and wavelength of measurement source;
- launch conditions;
- details of computation technique;
- date of latest calibration of equipment.

See annexes A, B, C, D and E for any additional information that shall be available upon request.

9 Specification information

The detail specification shall specify the following information:

- type of fibre (or cable) to be measured;
- failure or acceptance criteria;
- information to be reported;
- deviations to the procedure that apply.

Annex A
(normative)

Requirements specific to method A – Delay measuring

A.1 General

Use this method to measure the length of optical fibre by itself, or installed in cable. If the specimen is a fibre in a cable, determine the value of group index N under conditions applicable to the specimen under measurement (for example, tension, temperature). This is done by inverting equation (A.1) and the measurements on a specimen with a known length.

A.2 Principle

An optical pulse travelling through an optical fibre with length L and average group index N experiences a travelling/delay time, Δt:

$$\Delta t = \frac{NL}{C} \tag{A.1}$$

where

Δt is the time delay;

N is the average group index;

C is the velocity of light in vacuum.

If N is known, the measurement of Δt gives L. On the other hand, the measurement of Δt gives the value of N when L is known.

A.3 Apparatus

A.3.1 Two techniques

There are two techniques for measuring the propagation time of an optical pulse:

- time measurement of the transmitted pulse (Δt measured);
- time measurement of the reflected pulse ($2\Delta t$ measured).

See figures A.1 and A.2 for two different arrangements corresponding to the two techniques applying a sampling oscilloscope.

Instead of the sampling oscilloscope, backscattering equipment, or a counter with separate start/stop gate and averaging capability (for example, at least 10^4 counts), can be used.

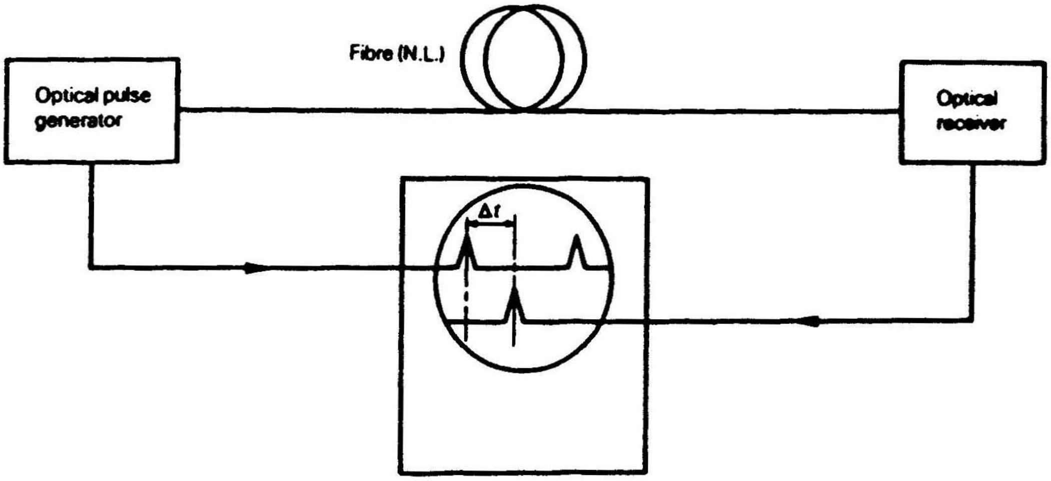

Figure A.1 – Time measurement of the transmitted pulse

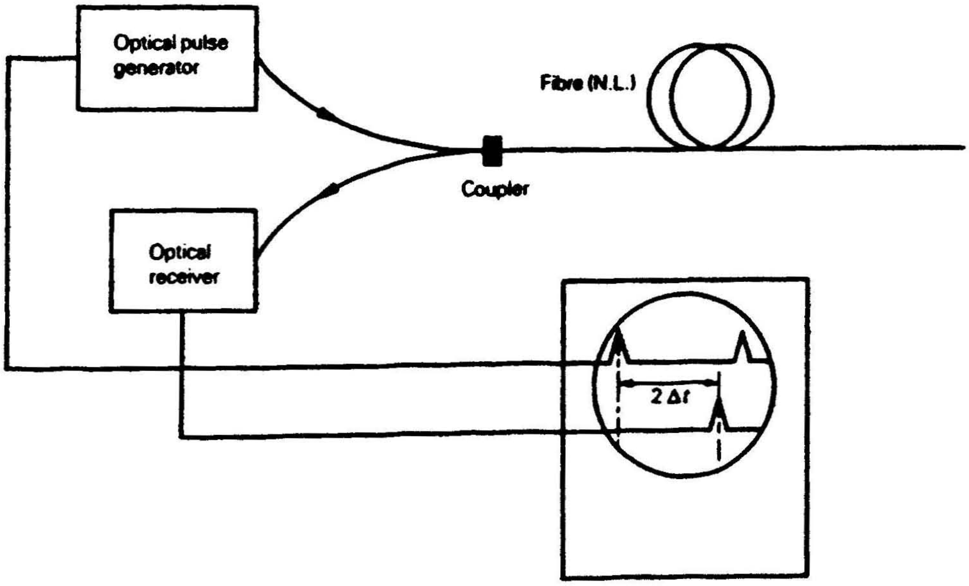

Figure A.2 – Time measurement of the reflected pulse

A.3.2 Optical source

A.3.2.1 Measurement with the sampling oscilloscope

An optical pulse generator shall preferably be a high-power laser diode, excited by an electrical pulse train generator, tunable in frequency and width. Record the wavelength and the spectral width.

A.3.2.2 Measurement with a counter or a backscattering apparatus

An optical pulse generator shall preferably be a high-power laser diode, excited by an electrical pulse train generator, tunable in width. The time between two pulses shall be longer than the travelling time of the transmitted pulse (Δt, with counter) or the reflected pulse ($2\Delta t$, with backscattering equipment). Record the wavelength and the spectral width of the laser diode.

A.3.3 Optical detector

The receiver shall preferably be a high-speed avalanche photodiode. The sensitivity of the optical detector shall be sufficient at the measuring wavelength, and its bandwidth shall be large enough so as not to influence the shape of the pulse.

A.4 Procedure

A.4.1 Calibration

Measure the delay time of the optical source to the launching point (this is the delay time of the measurement apparatus itself).

A.4.2 Average group index value

On a known length of mechanically measured fibre, the measurement of Δt, gives the average value, N, of the group index of the fibre.

A.4.3 Length measurement

The length measurement is a time-domain reading on the screen of an oscilloscope (or the reading of the averaged travelling time on the display of an electronic counter to be corrected for the calibration value).

NOTE See figure A.3 for an illustration of an important practical improvement for achieving the accuracy of the measurement, independent of the actual length of the fibre specimen. This uses a dual-channel approach.

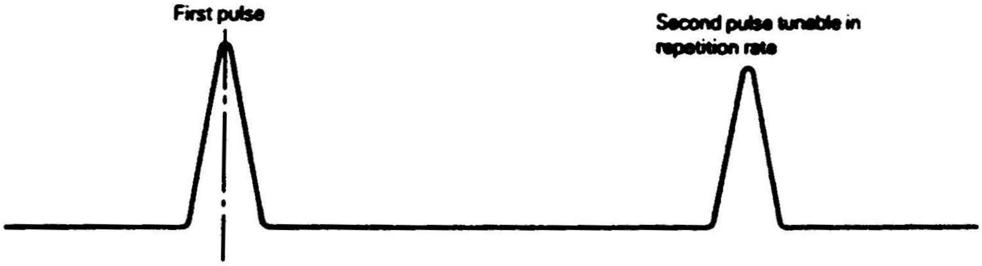

Figure A.3a – Channel 1: emitted pulse

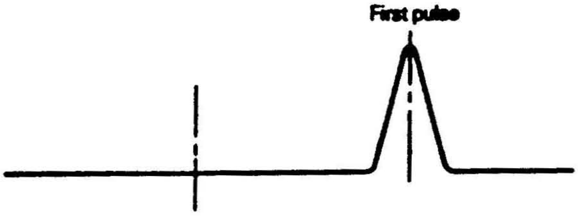

Figure A.3b – Channel 2: transmitted pulse

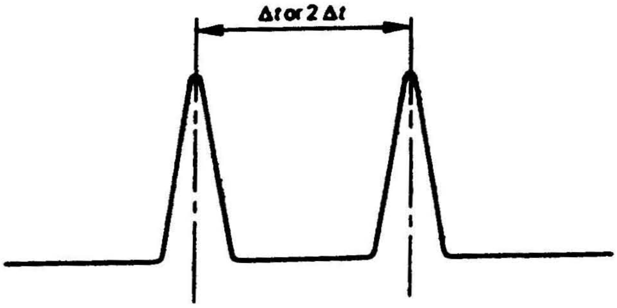

Figure A.3c – Emitted pulse after adjustment of the repetition rate in such a way that the second pulse of channel 1 coincides with the transmitted pulse of channel 2

Figure A.3 – Principle of fibre-length measurement

A.5 Calculations

Obtain the fibre length from one of the following equations:

A.5.1 Transmitted-pulse technique

$$L = \frac{\Delta t \times c}{N} \qquad \text{(A.2)}$$

A.5.2 Reflected-pulse technique

$$L = \frac{\Delta t \times c}{2N} \qquad \text{(A.3)}$$

where

L is the fibre length, in m;

Δt is the transmission or reflection time, in ns;

c is the light velocity in vacuum, in m/ns;

N is the average group index.

A.6 Results

In addition to the results in clause 8, the following information shall be available upon request:

- average group index;
- delay time of the measurement apparatus (optional);
- transmission or reflection time (optional).

Annex B
(normative)

Requirements specific to method B – Backscattering

B.1 General

This method uses an OTDR to measure the length of optical fibre by itself and installed in cable.

B.2 Apparatus

This method uses an optical time-domain reflectometer (OTDR), which shall normally consist of the following minimum list of components. See figure B.1 for a block diagram.

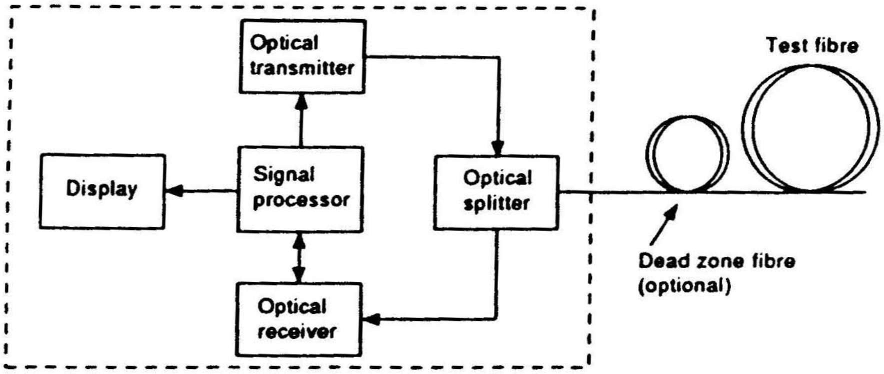

Figure B.1 – Block diagram of an OTDR

B.2.1 Optical transmitter

This usually includes one or more pulsed laser diode sources capable of one or more pulse durations and pulse repetition rates. Unless otherwise specified in the detail specification, the spectrum for each wavelength shall satisfy the following.

B.2.1.1 The central wavelength shall lie within 15 nm of the specified value; report the difference between the central wavelength and the specified value if it is greater than 10 nm.

B.2.1.2 The root-mean-squared width (RMSW) shall not exceed 10 nm, or the full-width at half maximum (FWHM) shall not exceed 25 nm.

B.2.1.3 If the data are to be used in a spectral attenuation model:

- the spectral width shall not exceed 15 nm (FWHM) or 6 nm (RMS) for wavelengths in the water peak region (e.g. 1 360 nm to 1 430 nm);
- report the actual central wavelength to within 2 nm of the actual value.

B.2.2 Launch conditions

Provide a means for connecting the test fibre (or the optional dead-zone fibre of B.2.9) to the instrument panel, or to a fibre pigtail from the source.

For type A fibre, optical sources may not produce launch conditions that are well controlled or appropriate to this measurement method. Therefore, unless otherwise specified in the detail specification, launch conditions for attenuation measurements shall be those used in cut-back attenuation measurements (IEC 60793-1-40 method A).

B.2.3 Optical splitter

A coupler/splitter within the instrument directs the power from the transmitter into the fibre. It also directs light returning in the fibre from the opposite direction to the receiver.

B.2.4 Optical receiver

This usually includes a photodiode detector having a bandwidth, sensitivity, linearity and dynamic range compatible with the pulse durations used and signal levels received.

B.2.5 Pulse duration and repetition rate

The OTDR may be provided a choice of several pulse durations and repetition rates (sometimes coupled to the distance control) to optimize the trade-off between resolution and range. With a high amplitude reflection, it may be necessary to set the rate or range to a value exceeding twice the distance of the reflection in order to prevent spurious 'ghost' images. Pulse coding techniques may also be used.

NOTE Care should be taken when selecting the pulse duration, repetition rate and source power. For shorter distance measurements, short pulse durations are necessary in order to provide adequate resolution. This in turn will limit dynamic range and maximum measurable length. For long length measurements, the dynamic range can be increased by increasing the peak optical power up to a level below which non-linear effects are insignificant. Alternatively, pulse width can be increased, which will reduce the resolution of the measurements.

B.2.6 Signal processor

If required, the signal-to-noise level may be increased by the use of signal averaging over a longer measurement time.

B.2.7 Display

This is incorporated into the OTDR and is part of the equipment controlling the OTDR. The OTDR signal is displayed in a graphical form with the vertical scale as decibels and the horizontal scale as distance. The vertical decibel scale shall correspond to half the round-trip of the backscatter loss. The horizontal scale shall correspond to half the associated (round-trip) optical group delay, converted to distance. Tools such as cursors may be used to manually or automatically measure all or part of the OTDR trace on the display.

B.2.8 Data interface (optional)

The instrument may be capable of interfacing with a computer for automatic analysis of the signal or for providing a hard copy of the display trace.

B.2.9 Reflection controller (optional)

Means of minimizing transient saturation of the receiver due to high Fresnel reflections may be required to reduce the length of fibre "dead zone" following each reflector. This can be incorporated into the coupler/splitter, or may be done by electronic masking. To overcome the initial reflection at the OTDR connector, a dead-zone fibre (with a length in metres numerically exceeding one-tenth the displayed pulse duration in nanoseconds) may be used between the OTDR connector and the specimen.

B.2.10 Splices and connectors

Unless otherwise indicated in this procedure, any splices or connectors required by the OTDR (e.g. to join the OTDR or the dead-zone fibre to the test fibre) shall have low insertion loss and reflectance (high return loss). This is to minimize extraneous effects upon the OTDR trace of interest.

B.3 Sampling and specimens

The sample comprises a fibre on a reel or within a cable, under conditions specified in the detail specification. The measurement may be performed in the factory or in the field, upon either single or concatenated sections.

NOTE Care should be taken to ensure that winding does not introduce substantial elongation for length measurements.

B.4 Procedure

B.4.1 Three techniques

There are three techniques:

- two-point technique (B.4.3.1), to use when a fibre or cable section of unknown length precedes the test fibre or cable;
- single-point technique 0 (B.4.3.2), to use with no preceding section of fibre or cable;
- single-point technique 1 (B.4.3.3), to use with a preceding section of fibre of known length and similar group index as the fibre to be measured.

NOTE For cable measurement, it is important to note that, due to the structure of most cables, there is an excess length of fibre in the cable. Because of this, the cable group index exceeds the fibre group index for the same fibre type. This will lead to discrepancy between the fibre length in the cable and the cable length itself.

B.4.2 Procedure common to all three techniques

B.4.2.1 Connect the specimen either to the instrument or to one end of the dead-zone fibre (if used). Connect the other end of the dead-zone fibre (if used) to the instrument.

B.4.2.2 Because accurate distances are to be recorded, the effective group delay index of the specimen is required. If this value is not known, use the method described in B.4.4 to determine it.

B.4.2.3 Enter OTDR parameters such as source wavelength, pulse duration, length range and signal averaging into the instrument, along with the specimen group index. The values of some of these parameters may be preset in the instrument.

B.4.2.4 Adjust the instrument to display a backscatter signal from the specimen. It may be advantageous to begin with coarse vertical and horizontal scaling in order to maximize the length displayed.

B.4.2.5 If increased resolution is needed, adjust the graphical display, if possible, to expand the section of interest to a larger scale (exercising care to ensure that proper readings of the true signal can still be distinguished from the noise points).

B.4.3 Procedures specific to each technique

B.4.3.1 Two-point technique

B.4.3.1.1 Place a cursor at the beginning of the trace of the specimen prior to any power drop-off (which may be difficult to do) (figure B.2), or at a point (which may be specified by the manufacturer) on the rising edge of the reflection pulse (figure B.3). If the beginning is not apparent because of minimal discontinuity, apply a tight bend at this location and vary the radius to assist in cursor placement. Obtain the distance coordinate, z_1, via the alphanumeric display.

B.4.3.1.2 Place the same or another cursor at the end of the trace of the specimen at a point similar to that in B.4.3.1.1. If the end is not apparent due to minimal discontinuity, apply a tight bend at this location and vary the radius to assist in cursor placement. Alternatively, cleave the fibre far-end, if possible, to produce a reflection there. If the end is below the noise floor, the length measurement may have a maximum error equal to the pulse length. Obtain the distance co-ordinate, z_2.

B.4.3.1.3 For maximum length accuracy, the nature of the drop-off or rise-time points at z_1 and z_2 should be similar. Obtain the specimen length, $(z_2 - z_1)$.

B.4.3.2 Single-point technique 0

Use this method when no fibre or cable section (or dead-zone fibre) precedes the specimen. See figure B.4.

B.4.3.2.1 Place a cursor at the end of the trace of the specimen prior to any power drop-off (which may be difficult to do), or at a point (which may be specified by the manufacturer) on the rising edge of the reflection pulse. If the end is not apparent because of minimal discontinuity, apply a tight bend at this location and vary the radius to assist in cursor placement. If the end is below the noise floor, the length measurement may have a maximum error equal to the pulse length.

Alternatively, cleave the fibre far-end, if possible, in order to produce a reflection there. Obtain the distance coordinate, z_2.

B.4.3.2.2 The specimen length equals z_2.

B.4.3.3 Single-point technique 1

Use this method when a fibre or cable section (or a dead-zone fibre) of known length, z_D, precedes the specimen. See figure B.5. The length may be obtained by mechanical measurement, for example by using contact-type devices with counters.

NOTE The fibre used in the preceding section (or dead-zone fibre) should have a similar group index as the specimen.

B.4.3.3.1 Perform the steps of B.4.3.2.1.

B.4.3.3.2 The specimen length equals (z_2 − z_D).

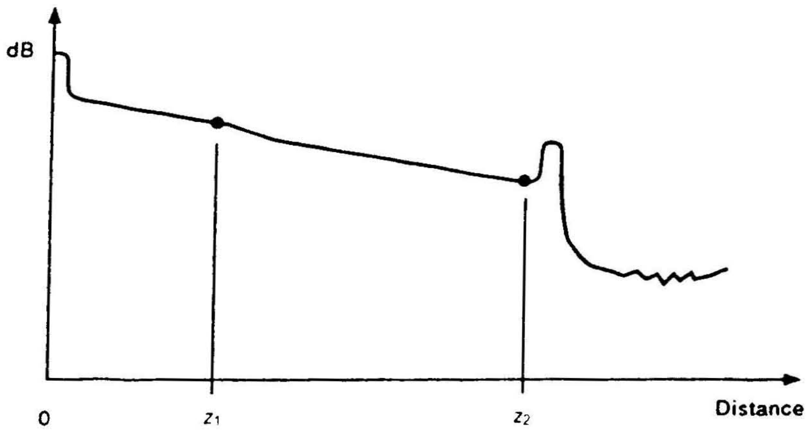

Figure B.2 – Schematic OTDR trace of a specimen (z_1 to z_0) with a section (e.g. dead-zone fibre) of unknown length, z_1, preceding it and without a reflection pulse from the fibre joint point (two-point technique (B.4.3.1))

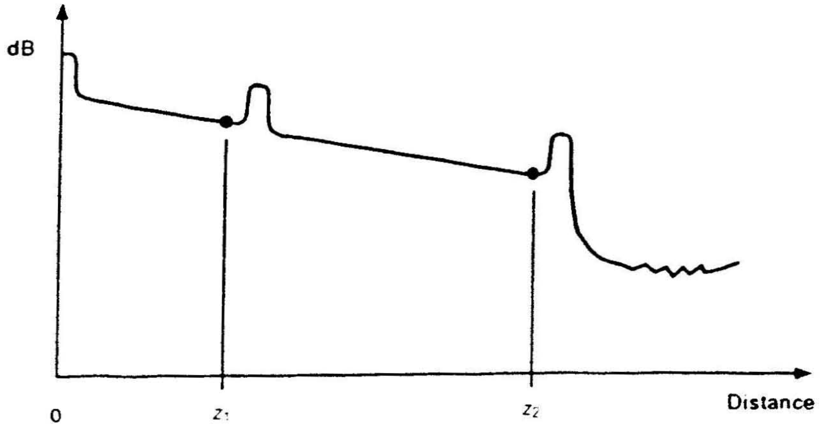

Figure B.3 – Schematic OTDR trace of specimen (z_1 to z_2) with a section (e.g. dead-zone fibre) of unknown length, z_1, preceding it and with a reflection pulse from the fibre joint point (two-point technique (B.4.3.1))

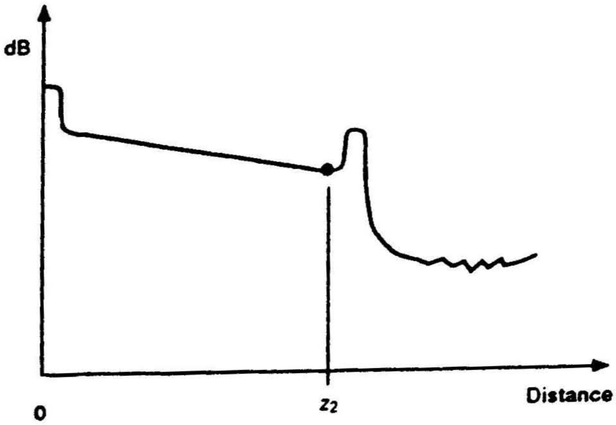

Figure B.4 – Schematic trace of a specimen (0 to z_2) with no section preceding it (single-point technique (B.4.3.2))

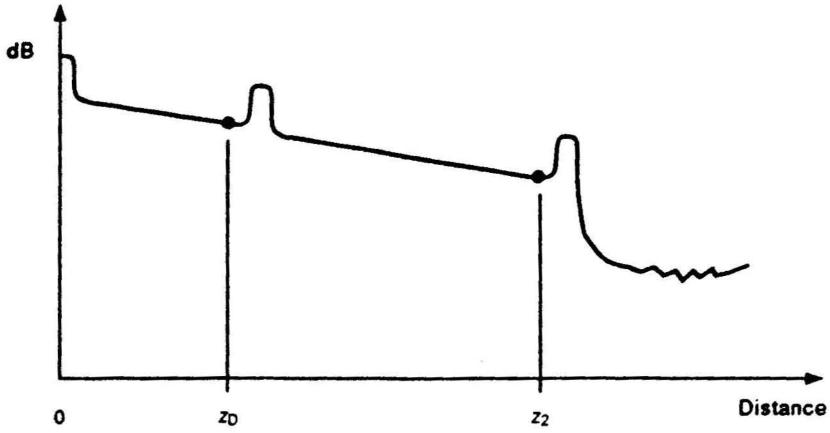

Figure B.5 – Schematic OTDR trace of a specimen (z_D to z_2) with a section (e.g. dead-zone fibre) of known length, z_D, preceding it (single-point technique (B.4.3.3))

B.4.4 Determination of group index

B.4.4.1 Accurately determine the physical length of the calibration fibre or cable. This may be done by mechanical measurement, for example by using contact-type devices with counters.

B.4.4.2 Perform the steps given in B.4.2.1 for the calibration fibre or cable.

B.4.4.3 Perform the steps given in B.4.2.3, but with an arbitrary group index.

B.4.4.4 Place one cursor at the beginning of the trace as indicated in B.4.3.1.1. Obtain the distance coordinate, z_1, via the alphanumeric display.

B.4.4.5 Place another cursor at the end of the trace as indicated in B.4.3.1.2. Obtain the distance coordinate, z_2.

B.4.4.6 Adjust the group index scale until the difference, $(z_2 - z_1)$, which may be automatically calculated by the instrument, equals the length determined in B.4.4.1..

B.5 Results

In addition to the results in clause 8, the following information shall be available upon request:

group index.

Annex C
(normative)

Requirements specific to method C – Fibre elongation

C.1 Principle

Derive the fibre elongation by the phase shift technique (C.2.2.1), or by the differential pulse delay (C.2.2.2).

The fibre elongation strain, $\varepsilon = \Delta L/L$, is given by:

$$\varepsilon = V \times \frac{\Delta t}{L} \tag{C.1}$$

where

Δt is the differential pulse delay;

L is the specimen fibre length;

V is a constant that depends on the photoelastic coefficient (k), the speed of light in a vacuum (c), and the group index of refraction (N_{eff}).

$$V = \frac{kc}{N_{eff}} \tag{C.2}$$

The factor, V, corrects the results for changes in the fibre's refractive index with strain.

When using the phase-shift technique (C.2.2.1), derive the differential delay, Δt, from:

$$\Delta t = \frac{\Delta\Theta}{360 \times f} \tag{C.3}$$

where

$\Delta\Theta$ is the phase shift (degrees);

f is the modulation frequency.

Because the factor, V, depends on the fibre type, the measurement set-up shall be calibrated.

C.2 Apparatus

C.2.1 General requirements

The measurement fixture of known gauge length shall be capable of applying and varying longitudinal stresses on the cable or fibre. Observe the proper fixing of the ends of the specimen in order to prevent the fibres from slipping during loading. Provide a suitable elongation bench for the calibration of the phase-shift or pulse-delay versus the mechanically measured fibre elongation.

C.2.2 Optical measurement equipment

The equipment for either technique, phase shift technique or differential pulse delay, should be stable over the measurement time period and temperature range encountered. See figures C.1 and C.2, respectively, for diagrams of typical equipment set-ups.

C.2.2.1 Phase-shift technique

Use a light source (either a laser diode or filtered light-emitting diode), modulator, launch optics, signal detector and reference signal for measuring chromatic dispersion using the phase-shift technique. These pieces of equipment are outlined and specified in method A of IEC 60793-1-42. The difference is that only one laser diode is used. The phase shifts observed are a function of strain changes on the fibre.

NOTE Care should be exercised in observing that 360° phase-shift roll-over ambiguities of the phase meter are accounted for when using this method.

C.2.2.2 Pulse-delay (time of flight) technique

Use equipment required for an appropriate time-of-flight measurement technique, such as a short-pulse/Fresnel optical time domain reflectometer (OTDR).

C.2.3 Instrument resolution

The strain measurement resolution of the entire measurement system should be equal to or less than 0,01 %. This includes the optical measurement equipment (modulation frequency or pulse width, etc.) and the measurement fixture (specimen gauge length, cable/fibre end fixers, load measurement, etc.). Since all of these factors are involved in determining the entire measurement system's accuracy and resolution, each measurement bench should be evaluated separately.

This measurement procedure is intended to be conducted at ambient room conditions typically found in laboratories. This method is feasible under other conditions, provided the temperature is stable to ±2 °C for the duration of the test. For extreme temperature and pressure changes (more than 40 atmospheres), corrections may be necessary, particularly with regard to the *V* factor.

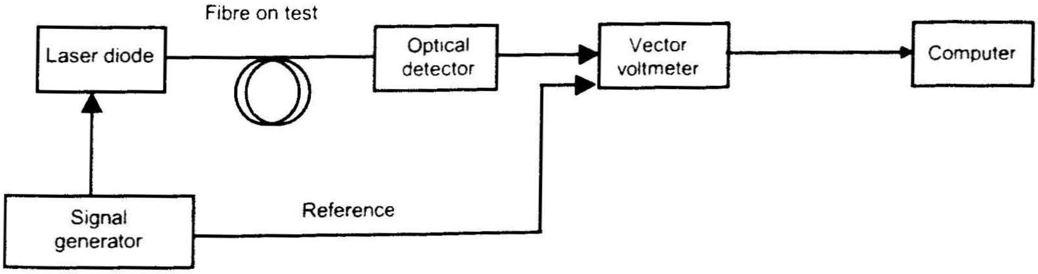

Figure C.1 – Equipment set-up for phase-shift technique (C.2.2.1)

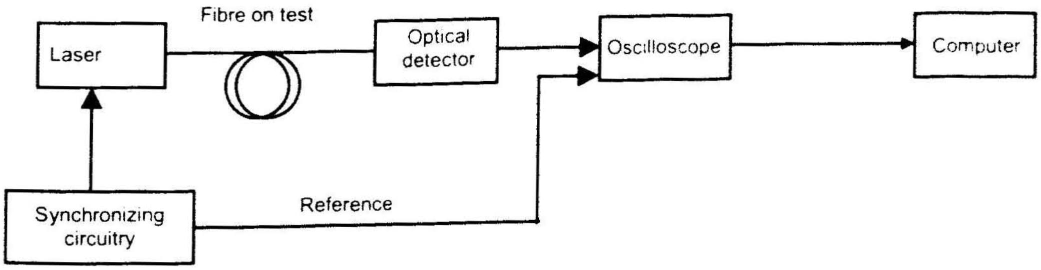

Figure C.2 – Equipment set-up for differential pulse-delay technique (C.2.2.2)

C.3 Procedure

C.3.1 Calibration

Install the reference fibre on the elongation bench and connect it to the optical measurement apparatus.

Progressively increase the fibre elongation within a known range of elongation that is sufficiently linear to determine the factor, V.

Measure and record, preferably continuously, the phase shift or pulse delay as a function of the mechanical fibre elongation.

The relation thus determined accounts for the strain-induced changes of the group index.

NOTE 1 It is recommended that the operator carry out the calibration with a random selection of fibre samples of the same type

NOTE 2 It is not necessary to repeat this calibration before each fibre elongation measurement, as long as the same type of fibre (design and manufacturer) is used.

C.3.2 Specimen measurement

Take either a phase reading in degrees or time-delay reading for the reference condition (typically ambient conditions) Record the reference value. Longitudinally strain the specimen to the specified load. After the applied load is stabilized, repeat the measurement procedures and record either the strained phase value or length value. Repeat these steps for any additional load conditions. Upon releasing the applied load, take a final measurement to ensure that the applied fibre strain has returned to its original reference condition.

NOTE Perform a single-end measurement using one of the techniques shown below. If the phase-shift technique is used, the phase should be continuously recorded while applying the load to account for 360° phase-shift roll-overs.

a) For a cable under test, form an optical path by two fibres that are connected together at the far end. However, due to the averaging effect of the strains on the two fibres, take particular care when interpreting the results.

b) Insert, at the near end, a suitable directional coupler connected, on one side, to the optical source and to the detector, and, on the other side, to the fibre under test. Then measure the phase shift or pulse delay between the input signal and the signal reflected from the far end. The cleaved fibre far end face shall be clean and perpendicular in order to maximize the reflected signal. Take care to minimize other reflections (e.g. from the near end of the fibre).

In both cases, use a factor 2 to correct the collected phase-shift or pulse-delay data in order to take into account the double length of the optical path.

C.4 Results

In addition to the results in clause 8, the following information shall be available upon request:

- load applied at each phase (or length) reading, and the calculated strain;
- type and frequency of modulator (phase-shift method).

Annex D
(normative)

Requirements specific to method D – Mechanical length

D.1 Principle

This method of measuring fibre length is carried out by winding the fibre onto a spool. It may be done on the draw, during the tensile-proof operation, or any other such winding process. During the process, the fibre engages with a fixed diameter calibrated wheel that rotates. The number of revolutions resulting from the winding process, multiplied by $\pi D/1\ 000$, yields the length of the fibre in kilometres, where D is the diameter of the counting wheel, in metres.

D.2 Apparatus

Provide a wheel, or arrangement of wheels, so that the passage of fibre length through the assembly is linked to the counter wheel rotation in a linear fashion. Take care to ensure that no slippage of the fibre relative to the surface of the counting wheel occurs.

The counter wheel shall be rigid, with a surface that is free of burrs or other features that can damage the fibre. Link the counter wheel with an electronic counter that may optionally convert counts to length.

D.3 Procedure

D.3.1 Calibration

Calibrate the wheel by passing a fibre of known length (calibration fibre) through the winding process This can correct for variations in wheel surface treatment or wheel machining.

Use surveying equipment to obtain length measurements on the calibration fibre. Use a fibre of a length that is long enough for the desired accuracy. When being measured, deploy it in a straight line and measure it at a temperature that is consistent with the operating temperature of the mechanical measurement device.

D.3.2 Operation

Reset the counter and initiate the winding process. At the completion of the winding process, note the count and convert to length.

NOTE Care should be taken to ensure that winding does not introduce substantial elongation and that elongation conditions are the same during calibration

Annex E
(normative)

Requirements specific to method E – Phase shift

E.1 General

This test method uses the phase shift change in an optical fibre or cable when the frequency is increased to a predetermined modulation frequency f_{max}. It may be applied to fibre lengths typically in the range of less than 1 m to several kilometres for type A1 fibres and to several hundreds of kilometres for type B fibres.

E.2 Apparatus

A diagram of the measurement apparatus is shown in figure E.1. The apparatus used in this measurement method may also be configured to measure the chromatic dispersion of a fibre. Measurement of chromatic dispersion by the phase shift method is described in method A of IEC 60793-1-42.

E.2.1 Light source

Either a laser diode or a filtered light-emitting diode may be used. The centre wavelength and modulated output phase shall be stable over the measurement time period at the bias current, modulation frequency and diode temperature range encountered.

The spectral width of the source at full-width half-maximum (FWHM) shall be less than or equal to 30 nm. This may be achieved using a monochromator or optical filter, if necessary.

E.2.2 Modulator

Provide a means to modulate the intensity of the output of the optical source over a wide frequency range, typically from about 100 Hz up to a few gigahertz, to produce a waveform that has a single dominant Fourier component, such as a sine wave.

The choice of modulation frequency is determined by the maximum fibre length that is to be measured and the measurement precision that is required. In order to avoid ambiguities caused by 2π phase shifts, where there is more than one complete modulation cycle in the fibre, it is necessary to start with a low frequency and count the number of complete cycles as the frequency is slowly increased. It is important that the number of 2π phase shifts are counted unambiguously. The use of a higher frequency usually gives a more precise measurement of length. For a given fibre length L, in metres, the maximum starting frequency f_{start}, in hertz, is given by

$$f_{start} \leq \frac{c}{N \times L} \qquad \text{(E.1)}$$

where

c is the velocity of light in a vacuum, in m/s;

N is the group index.

For example, for a length of 10 km a typical maximum value of f_{start} would be 20 kHz.

Alternatively, if the starting frequency has already been chosen then the maximum length of fibre that can be measured may be calculated from a re-arrangement of equation (E.1).

The choice of upper frequency, the corresponding phase noise at this frequency and the uncertainty of the modulation frequency itself will determine the measurement resolution. For a minimum measurable phase change of $\Delta\phi$, in radians, the minimum resolvable length ΔL, in the absence of phase noise and frequency uncertainty, is given by

$$\Delta L = \frac{\Delta\phi \times c}{f_{\max} \times N \times 2\pi} \qquad (E.2)$$

Note that the value of $\Delta\phi$ may depend on the modulation frequency used.

Alternatively, for a given fibre length resolution, then the maximum frequency required may be determined from a re-arrangement of equation (E.2).

For example, for a phase resolution of 0,01 rad and a maximum frequency of 100 MHz, the length resolution would be approximately 3 mm.

E.2.3 Launch optics

Couple light from the source into the fibre under test by, for example, optically imaging the source onto the end of the test fibre or by direct butt coupling from a fibre pigtail that is coupled to the source. For type A1 fibres it is necessary to restrict the launch conditions so as to excite only low-order modes in the fibre, in order to minimise the effects of modal dispersion. This may be achieved either by direct imaging of the source onto the end of the test fibre using an optical system in which the numerical aperture and the spot-size may be restricted, or by direct coupling from a single-mode fibre pigtail which is positioned on the axis of the test fibre and in contact with it.

E.2.4 Signal detector and signal detection electronics

For signal detection use an optical detector that is sensitive at the wavelength of measurement, is stable over the duration of the measurement, and is linear over the intensity modulation range. An amplifier may be used to increase detection sensitivity. Couple light from the test fibre onto the detector using, for example, direct imaging with lenses or a fibre pigtail that is directly coupled to the detector. For type A1 fibres it is necessary to collect only light from low-order modes in the test fibre. This may be achieved by direct imaging onto the detector using an optical system in which the numerical aperture and the spot-size may be restricted, or by direct coupling into a single-mode fibre pigtail which is positioned on the axis of the test fibre and in contact with it.

Use a phase-measuring instrument, such as a phase meter, vector voltmeter or network analyzer, that responds only to the fundamental Fourier component of the modulating signal to determine the phase of the detected light. Any phase shift that is introduced by the phase measuring system itself shall be constant for the duration of the measurement.

E.2.5 Reference signal

A reference signal is required by the phase meter, which has the same dominant Fourier component as the modulating signal, against which the phase of the output signal is measured. The reference signal shall be phase locked to the modulating signal. The reference signal may be derived by either taking a direct electrical connection from the modulation source to the phase meter, or by using a detector coupled to an optical beam splitter or fibre coupler which is inserted between the source and the test fibre.

E.2.6 Computation equipment

A computer may be used for the purposes of equipment control, data acquisition and numerical evaluation of data.

E.3 Sampling and specimens

The test sample shall be a fibre which may, or may not, be cabled. Typical fibre sample lengths are 1 m to hundreds of kilometres. The sample, launch optics and pigtails, if used, shall be fixed in position at a nominally constant temperature for the duration of the measurement. In the case of installed fibres and cables, the prevailing deployment and environmental conditions may be used.

Either a phase calibration fibre of the same type as the fibre under test, (or the fibre pigtails, if used), is required to compensate for phase shifts that may be introduced by the phase meter or internal optical path lengths. A typical length is 0 m to 2 m.

Prepare end faces for the input and output ends of the calibration fibre and test fibre, as appropriate for the requirements of E.2.3 and E.2.4.

E.4 Procedure

E.4.1 Selection of starting frequency

Select a suitably low modulation frequency f_{start}, determined using equation (E.1). If the approximate length of the fibre is unknown then use the lowest available modulation frequency but exercise caution with respect to the possibility of 2π phase errors in the fibre.

E.4.2 Selection of maximum frequency

Select a suitable maximum frequency f_{max}, determined using equation (E.2), for the required length resolution.

E.4.3 Phase measurement performance

This subclause applies to all length measurements made on the test fibre and the phase calibration fibre, and also, if required, during the determination of group index.

Starting at modulation frequency f_{start} increase the frequency, until f_{max} is reached, at a rate sufficient to allow the unambiguous determination of the number, m, of 2π phase shifts that occur. Measure the phase angle ϕ' at the output of the fibre at f_{max}.

Calculate the total phase angle ϕ as follows:

$$\phi = \phi' + m \times 2\pi \qquad \text{(E.3)}$$

E.4.4 Measurement of length of test fibre

E.4.4.1 Calibration of reference phase

Depending on whether fibre pigtails are used or not, calibrate the reference phase by following one of the two methods below:

a) When pigtails are not used, couple one end of the phase calibration fibre (input) to the light source. Couple the other end (output) to the detection system. Measure the phase shift ϕ_{ref} according to E.4.3.

b) When pigtails are used at both the launch and receive ends, these are connected together to perform the reference phase measurement instead of using a separate phase calibration fibre. Measure the phase shift ϕ_{ref} according to E.4.3.

It is sometimes convenient to remove the phase calibration fibre and/or the pigtails from the apparatus after the reference measurement has been made. This may be done provided that the phase shift that occurred within the phase calibration fibre and/or the pigtails is known and is subsequently added to the measured phase shift of the fibre under test, see E.4.4.2.

NOTE It is not normally necessary to calibrate the reference phase before each and every measurement. The use of a stored reference value is permitted provided that it is understood that the presence of phase drift in the system may degrade the measurement uncertainty.

E.4.4.2 Measurement of test fibre phase

Depending on whether fibre pigtails are used or not, measure the test fibre phase by following one of the two methods below.

a) When pigtails are not used, uncouple the output of the phase calibration fibre from the detection system and couple it to one end of the fibre under test (input). Couple the other end (output) of the fibre under test to the detection system. Measure the phase shift ϕ_{sig} according to E.4.3 using the same value of f_{max} used E.4.4.1.

b) When pigtails are used instead of a phase calibration fibre, disconnect the pigtails from each other and couple the free ends to the fibre under test. Measure the phase shift ϕ_{sig} according to E.4.3 using the same value of f_{max} used in E.4.4.1.

E.5 Calculation and interpretation of results

E.5.1 Determination of test fibre length

Calculate the length, L, of the test fibre as follows:

$$L = \frac{(\phi_{sig} - \phi_{ref}) \times c}{N \times f_{max} \times 2\pi} \qquad \text{(E.4)}$$

where

L	is in metres;
ϕ_{ref}, ϕ_{sig}	are in radians;
c	is in metres per second;
f_{max}	is in hertz;
N	is the group index.

Note that ϕ_{ref} and ϕ_{sig} represent the total phase angle at the maximum frequency f_{max} used, including the total number of 2π phase shifts, see equation (E.3).

NOTE The group index N may be supplied by the fibre or cable manufacturer. The accuracy in measurement of length using this method largely depends on the certainty with which the group index is known. Group index values vary from fibre to fibre and may also be temperature sensitive. Typical manufacturers values have an uncertainty equivalent to 0.1 % in length measurement. If the group index is not known then it may be determined according to the procedure described in E.6.1.

E.6 Group index

E.6.1 Introduction

To determine the value of group index it is necessary to measure the phase shift associated with a fibre of known length at the wavelength of measurement. This may be performed either by cutting a known length of fibre from the output end of the test fibre, known as the cut-back method, described in E.6.2 or by connecting a fibre of known length, which is of the same class and type as the test fibre, to the apparatus in place of the test fibre, known as the substitution method, described in E.6.3.

NOTE Uncertainties due to non-linearities in the phase measurement system may be minimized by choosing cut-back and substitution fibre lengths corresponding to approximately one 2π phase cycle of the modulation frequency. For example, at a maximum frequency f_{max} of 100 MHz this corresponds to a length of approximately 2 m.

E.6.2 Cut-back method

E.6.2.1 Couple one end (input) of the test fibre to the light source. Couple the other (output) end of the test fibre to the detection system. Measure the phase shift ϕ_{long} according to E.4.3.

E.6.2.2 From the output end of the test fibre, remove a short length of fibre L_{cut} typically 2 m to 3 m (see E.6.1). Re-prepare the new output end of the test fibre, which is now slightly shorter, and couple it to the detection system. Measure the phase shift ϕ_{short} according to E.4.3 using the same value of f_{max} that was used in E.6.2.1.

E.6.2.3 Measure the length of the fibre L_{cut} that was removed in E.6.2.2 using, for example, a calibrated metre rule. Note that the uncertainty in this measurement will proportionally affect the measurement uncertainty of the group index of the test fibre.

E.6.2.4 Calculate the group index using equation:

$$N = \frac{(\phi_{long} - \phi_{short}) \times c}{L_{cut} \times f_{max} \times 2\pi} \qquad \text{(E.5)}$$

E.6.3 Substitution method

E.6.3.1 Couple one end (input) of the phase calibration fibre to the light source. Couple the other end (output) to the detection system. Measure the phase shift ϕ_{cal} according to E.4.3.

E.6.3.2 Uncouple the output of the phase calibration fibre from the detection system and couple a fibre of known length L_{sub}, typically 2 m to 3 m (see E.6.1), which is of the same class and type as the test fibre, between the output of the phase calibration fibre and the detection system. The length of this fibre may be measured with, for example, a calibrated metre rule. Measure the phase shift ϕ_{sub} according to E.4.3 using the same value of f_{max} used in E.6.3.1.

E.6.3.3 Calculate the group index using equation:

$$N = \frac{(\phi_{sub} - \phi_{cal}) \times c}{L_{sub} \times f_{max} \times 2\pi} \qquad \text{(E.6)}$$

The precision of the group index determination will affect the precision of the length as measured by phase shift method. Note, for very precise values, the group index value can vary from fibre to fibre, as well as with temperature and stress.

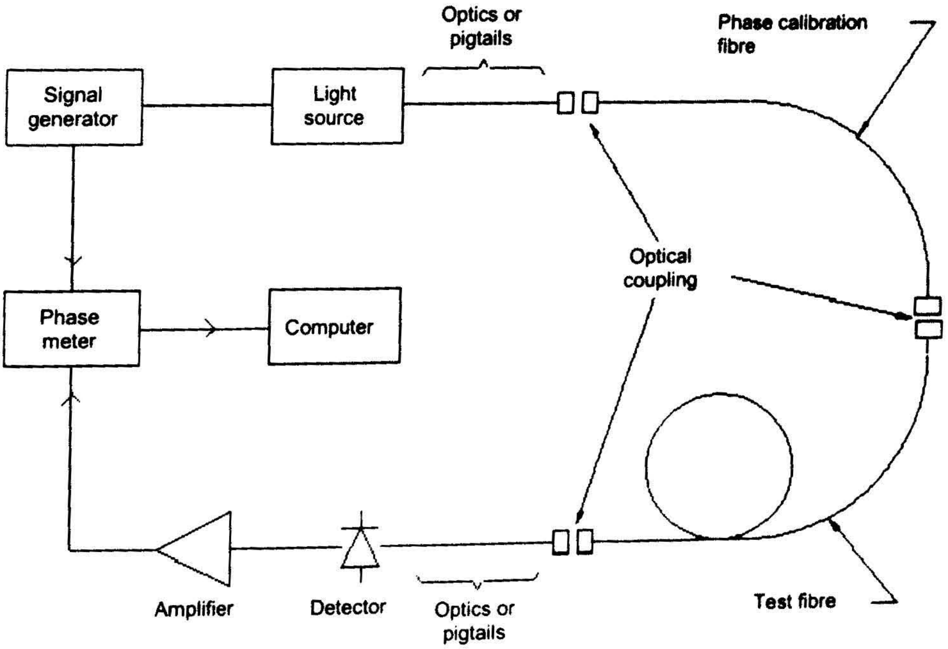

Figure E.1 – Apparatus for fibre length measurement

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